

Draft California Science Framework for K-12 Public Schools
January 25, 2002

Chapter 3 – The Science Content Standards
Grade Eight: Focus on Physical Science

INTRODUCTION

Eighth grade students study topics in physics such as motion, forces, and the structure of matter, using a quantitative, mathematically-based approach, similar to the procedures they will use in high school. Earth, the solar system, chemical reactions, chemistry of biological processes, The Periodic Table, and density and buoyancy are additional topics that will be treated with increased mathematical rigor, also in anticipation of high school courses. Students should begin to grasp four concepts that help to unify physical science: force and energy; the laws of conservation; atoms, molecules and the atomic theory; and kinetic theory. (See Appendix A.) These concepts serve as important organizers that will be required as students continue to learn science. Although much of the science called for in the standards is considered “classical” physics and chemistry, it should provide a powerful basis for understanding modern science and will serve students well as adults.

Mastery of the eighth grade physical science content will greatly enhance the ability of students to succeed in high school science classes. Modern molecular biology and earth sciences, as well as chemistry and physics, require that students have a good understanding of the basics of physical science.

STANDARD SET 1: Motion

Background

In ancient Greece, Aristotle wrote that a force is required to keep a body moving. Our everyday experience seems to confirm this misconception. For two thousand years, Aristotle’s description of motion was accepted without question. Then an experiment by Galileo resulted in the discovery of friction. Galileo’s experimental approach to investigating Nature helped establish modern science and led to the invention of calculus and Newton’s Laws of Motion. Four centuries after Galileo, our knowledge of motion enables us to predict and control the paths of far distant spacecraft with great accuracy. There are many types of motion: straight line, circular, back and forth, free-fall, projectile, orbital, etc. Standard Set 1 for eighth grade concerns itself with the motion of a body traveling either at a constant speed or with a varying speed that is represented by an average value.

Text of the Standards

1. The velocity of an object is the rate of change of its position. As a basis for understanding this concept:
 - a. Students know position is defined in relation to some choice of a standard reference point and a set of reference directions.

The position of a person or object must be described relative to a standard reference point. For example, the position of a bicycle may be “in front of the flagpole” or “behind the

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flagpole.” The flagpole is the reference point and "in front of" and "behind" are the reference directions. A reference point is usually called "the origin," and position can be given as a distance from the reference point together with a plus (+) or minus (-) sign that may stand for "in front of" and "behind," or "away from" and "toward," or "right" and "left," or one of any other pair of convenient, opposing directions from the reference point. To introduce the idea of measuring positions, distances and directions with respect to a standard reference point, meter sticks (or rulers) may be used. The students are directed to call the 50 cm mark (or some other convenient mark) the reference point. A position of -10 cm would be 10 cm to the left of the standard reference point; a position of +5 cm would be 5 cm to the right of the standard reference point. The teacher can call out various positive and negative position values, and the students should move their index fingers to that location. In particular, students can experience the fact that although moving their index fingers from -10 cm to -6 cm keeps their index fingers to the left of the origin, their index finger is moving to the right. Student in eighth grade should be able to track the motion of objects in a two- dimensional (x, y) coordinate system. For example both x and y could represent distances along the coordinate axis or the value of x could represent distance traveled and y could represent elapsed time.

- b. Students know that average speed is the total distance traveled divided by the total time elapsed and that the speed of an object along the path traveled can vary.

Speed is how fast something is moving with respect to some reference point without regard to the direction. It is calculated by dividing the distance traveled by the elapsed time. In the next standard students should learn to use SI units to measure distance in meters (m) and time intervals in seconds (s). In customary units, a car traveling 120 kilometers in 2 hours is traveling at a speed of 60 Km/hr. [Note that in everyday units speed is measured in miles per hour. In the school laboratory it may be more convenient to use centimeters instead of meters for distances and seconds for time, so speed would be given in centimeters per second (cm/s).] The speed of a spacecraft may be measured by how long it takes to orbit the earth and the length of that orbit. Sometimes the speed of an object remains constant while it is being observed but the speed of a vehicle usually changes during a trip. Students should be taught to recognize that the average speed of a vehicle is calculated by dividing the total distance traveled by how long it took to complete the entire trip. With several stops a trip of 100 miles from town A to town B might take 4 hours. The average speed is $100 \text{ miles} / 4 \text{ hours} = 25 \text{ miles per hour}$ even though at times the car may have had a speedometer reading of 55 mph.

Students can measure the total distance a toy vehicle or ball travels across the floor or table top after being released from the top of an inclined ramp (the standard reference point). They can also measure the time elapsed during the trip. The average speed can then be calculated by dividing the distance traveled (from the standard reference point) by the elapsed time. More than one student can be assigned to measure the times and distances so that duplicate data sets are created. The teacher can explore with the students why the data sets aren't exactly the same and help them evaluate the accuracy and reproducibility of the experiment. Note that the object's speed can be observed to change during the trip: it speeds up coming down the ramp due to gravity and slows down as it travels across the floor or table top due to friction. What is being calculated by $v = d/t$ (where v is the average speed, d is the total distance traveled and t is the elapsed time) is the average speed for the entire trip as if the object traveled at a constant speed. Students can change one of the conditions, such as the height of the ramp, to see how the

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average speed is affected. Or, students don't have to wait for the object to stop; they can measure the elapsed time from the top of the ramp to any point along the path prior to stopping to obtain the average speed between measurement points.

c. Students know how to solve problems involving distance, time and average speed.

Problems related to this standard may be solved using the traditional formula from math, $d = rt$, where "d" represents the total distance traveled, "r" stands for rate (or speed) and represents either the constant speed (if the speed is constant) or average speed (if it varies), and "t" represents how long the trip took. Given any two of these quantities, the third quantity can be calculated: $d = rt$, $t = d/r$, $r = d/t$. Students can be given information involving d, r or t about different segments of a real or hypothetical trip and asked to use the formula, $d = rt$, to solve for the missing information. To avoid confusion later, it is recommended that once students are familiar with this type of problem, the symbol "v" should be introduced for speed instead of r. (Note that when the vector nature of "velocity" needs to be introduced, the v will be written in bold-faced type, **v**, as will other vector quantities in the Framework.)

d. Students know the velocity of an object must be described by specifying both the direction and the speed of the object.

The word velocity has a special meaning in science. An air traffic controller needs to know both the speed and the direction of an aircraft (as well as its position), not just the speed. Those measurable quantities that require both the magnitude (we sometimes use size) and direction are vector quantities. Displacement, velocity, acceleration and force are all vector quantities and will be introduced in eighth grade using only one dimension or specified pathway. An arrow pointing in the direction of motion usually represents the velocity of an object. The length of the arrow is proportional to how fast the object is going (the speed). Students demonstrate mastery of this standard by knowing without prompting that they must specify both speed and direction when asked to describe an object's velocity.

e. Students know changes in velocity may be due to changes in speed, direction, or both.

Since velocity is a vector quantity, the velocity of an object is determined both by how fast the object is going and in what direction. Changing the speed of an object changes its velocity; changing the direction in which an object is traveling also changes the velocity. A change in either speed or direction (or both) will, by definition, change the velocity. (Although the term is not included in this standard set, it is useful to note that the rate at which a velocity changes with time is called acceleration. When a car speeds up or slows down it undergoes acceleration. When a car rounds a curve maintaining the same speed, it also undergoes acceleration because it changes direction.)

The important idea is that a change in the speed of the object. or in the direction of the motion of the object, or both is a change in velocity. It is easily understood that a change in the speed of an object causes a change in its velocity; it is less obvious to realize that a change in the direction of an object, with no change in the speed, also results in a change in the velocity of the object. Students need to recognize that spinning, curving soccer balls, baseballs or ping-pong balls may maintain a nearly constant speed through the air but change their velocity because they

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change direction. Of course an object can undergo a change in velocity in which both the direction and the speed change as when a driver applies the brakes while going around a curve.

In the next standard set students will learn that changes in velocity are always related to one or more forces acting on the object. Students learn to identify and find forces and their direction of action. Being able to recognize velocity changes of magnitude and direction are key to observing and characterizing forces.

- f. Students know how to interpret graphs of position versus time and graphs of speed versus time for motion in a single direction.

Students are required to apply the graphing skills they learned in lower grades to plotting and interpreting graphs of distance, location or position (d) versus time (t), and speed (v) versus time (t) for motion in a single direction. A major conceptual difference from the graphing skills learned in mathematics is that the two axes will no longer be number lines with no units. What must be explicitly addressed in dealing with motion graphs is plotting locations in distance units (m, cm, miles) on the vertical axis and plotting times in time units (s, m, h) on the horizontal axis. In plotting position versus time, the vertical axis represents distances away from an origin in the+ or - directions. The horizontal axis is the time. Every data point lying on the horizontal axis is “at the origin” because its distance value is zero. Given a graph of position versus time, students should be able to generate a table and calculate average speeds for any time interval ($v = d/t$). If the graph of position versus time is a straight line, the speed is constant, and students should be able to find the slope and know that the slope of the line is numerically equal to the value of the speed in units corresponding to the labels of the axes.

Students should know that a graph of speed versus time consisting of a horizontal line represents an object traveling at a constant speed and be able to use $d=rt$ to calculate the distance (d) traveled during a time interval (t). Students should know that a graph of speed versus time that is not a horizontal line indicates the speed is changing.

STANDARD SET 2: Forces

Background

The concept of force is central to the study of all natural phenomena that involve some kind of interaction between two or more objects whether or not visible motion occurs. For example, architects and civil engineers want their structures to stand firm against the forces of gravity, wind and earthquakes. Alternatively, automotive engineers need to know how best to accelerate a car, brake it to a safe stop, and smoothly change its direction. Students need to know that balanced forces keep an object from changing its velocity and that changes in the velocities of objects are caused by unbalanced forces.

There are only four known fundamental forces: gravitational forces, electro-magnetic forces, and two nuclear forces known as the strong and the weak force. Gravitational force is the attraction all objects with mass have for each. The common experience of gravity on Earth is only one example, the other pushes and pulls we normally experience are elastic forces caused by electromagnetic interactions between atoms and molecules being pushed together or pulled apart. The large, repulsive electrical forces between the positively charged protons in the

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nucleus of an atom are balanced against even stronger attractive nuclear forces that hold it together.

Students learned in second grade that the way to change how something is moving is to give it a push or a pull, e.g., apply a force. Magnets, compasses and static electricity in fourth grade gave students experience with electromagnetic forces. In seventh grade motion and forces were involved in comparing bones, muscles and joints in the body to machines.

Text of the Standards

2. Unbalanced forces cause changes in velocity. As a basis for understanding this concept:

a. Students know a force has both direction and magnitude.

Forces are pushes or pulls and, like velocity, are vector quantities described by the magnitude and the direction in which the force is acting. The direction and strength of a force may be indicated graphically by using an arrow. The length of the arrow is proportional to the strength of the force, and the arrow points in the direction of the force's application.

The simplest case to consider is that of forces acting along one line, such as to the left or to the right. These co-linear forces act either in the positive direction and are represented as positive quantities, or in the negative direction, and are represented as negative quantities.

A worthwhile activity is to have the students pull objects across level surfaces to measure the forces of friction. Different surfaces, because of varying roughness or different types of material, will exert different forces of friction on an object being dragged across them. If an object is pulled at a constant speed across a level surface, the force applied is just equal and opposite to the force of friction. If the force applied is greater than the force of friction, the object will speed up. If the force applied is less than the force of friction, the object will slow down. If the force applied is zero, the object will slow down and stop more quickly under the influence of the force of friction alone. Students can obtain data using a spring scale to measure the force and compare different objects on different surfaces.

b. Students know when an object is subject to two or more forces at once, the result is the cumulative effect of all the forces.

Forces acting along the same line on an object at the same time are algebraically added. For example, a force of 5 newtons acting in the positive direction (+ 5 N) and a force of 7 newtons acting in the negative direction (- 7 N) will result in an unbalanced force of 2 newtons acting in the negative direction (- 2 N). A force of one newton is close to the weight of a quarter-pound stick of margarine or butter, or that of a small apple. (In high school physics, students will learn that forces acting at different angles on an object can be broken down into components along the x-axis, y-axis and z-axis and that these components also add algebraically.)

c. Students know when the forces on an object are balanced, the motion of the object does not change.

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Several forces acting simultaneously on an object can add to zero. When this happens, there is no net force on the object and the motion of the object does not change. For example, a force of 10 newtons acting to the right (+10 N) and a second force of 10 newtons acting to the left (- 10 N) will add to zero, meaning there will be no change in the velocity of the object. Sometimes an object acted on by balanced forces is at rest and remains at rest. In a tug of war where both sides are pulling on a rope with equal force, the rope does not move.

Sometimes a moving object is acted on by balanced forces and continues to move at the same velocity. For example, we know that to push a book straight across a table at a constant velocity we must apply a force. Since the book does not speed up, slow down or change direction, we must conclude there is a frictional force pushing back on the book. Many people hold the misconception that a force is necessary to have an object maintain a constant velocity because the opposing force of friction is overlooked. Identifying and analyzing the forces acting on a sliding object by observing its velocity can help students develop their observation and analysis of frictional forces. If the motion (or velocity) is not changing, all the forces must be balanced. To be more complete, there are also two equal and opposed vertical forces (weight down and table up) acting on the book as well as the two equal and opposed horizontal forces (sliding push and friction) for a total of four forces.

- d. Students know how to identify separately the two or more forces that are acting on a single static object, including gravity, elastic forces due to tension or compression in matter, and friction.

The force of gravity pulls objects toward the center of the earth. This force of gravity is commonly called the weight of the object. If we drop an object, the force of gravity acting alone causes the velocity of the object to increase rapidly in the “down” direction. But, when we observe a single, static object, such as a book sitting motionless on a table, the table must be supplying a balancing upward force (an elastic force of compression caused by the compacting of the molecules of the table.) When we observe an object such as a yo-yo hanging motionless from a string, the string must be supplying a balancing upward force, an elastic force of tension as its molecules are stretched apart. A student may push gently on the book to move it horizontally across the table but the book does not move. The horizontal push cannot be the only force acting. There must be a second force pushing back to keep the book at rest. This opposing force is the force of friction between the molecules in the surface of the book and the surface of the table.

Resting a book on a meter stick spanning the gap between two student desks usually causes the meter stick to sag, showing that the meter stick flexes until the upward force from its elastic distortion is sufficient to support the book. A soft, dry sponge or spring could also show how elastic forces support a book against the downward pull of gravity.

- e. Students know that when the forces on an object are unbalanced, the object will change its velocity (that is, it will speed up, slow down, or change direction).

When an unbalanced force acts on an object initially at rest, the object moves faster in the direction of the applied force. If an object is already in motion, for example traveling to the right, and an unbalanced force acts to the right, the object will speed up. An object traveling to the right acted on by an unbalanced force to the left will slow down, and, if the unbalanced force

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continues to act, the object may slow to a stop and even begin to move faster in the opposite direction. If an unbalanced force acts in a direction perpendicular to the direction the object is moving, the force will deflect the object from its path, changing its direction, but not its speed along the curved path. Any force that does this, such as the force of the road on the tires of a car, is called a centripetal force. This force is directed to the center of the curved motion. Finally, an unbalanced force acting at an angle to the path may affect both the speed and the direction of the object.

Students should be able to predict changes in velocity if forces are shown to be acting on an object, and identify that an unbalanced force is acting on an object if they observe a change in its velocity. Students may not be able to fully explain the cause of the unbalanced forces that creates the baseball pitcher's curve ball, or the path of a spinning soccer ball, but they can state that there is a force acting perpendicular to the path of the ball.

- f. Students know the greater the mass of an object, the more force is needed to achieve the same rate of change in motion.

When the forces acting on an object are unbalanced, the velocity of the object must change by increasing speed, decreasing speed or altering direction. This also means that if an object is observed to speed up, slow down or change direction there must be an unbalanced force acting on it. The rate of change of velocity is acceleration. In high school, students will learn to solve problems using Newton's second law of motion which states that the acceleration of an object is directly proportional to the force applied to the object and inversely proportional to its mass. For now students should learn to recognize acceleration (or deceleration) and should be able to state the direction of the force and its relative magnitude that is the cause.

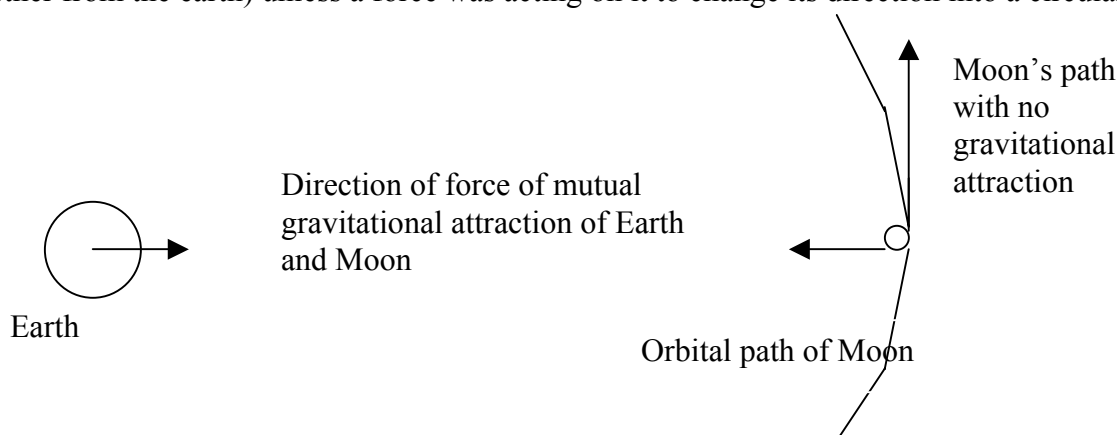
When an unbalanced force acts on an object, the velocity of the object can change slowly or rapidly. How fast the velocity of the object changes, that is the rate of change of velocity with time (called the acceleration), depends on two things: the size of the unbalanced force acting on the object and the mass of the object. The larger the unbalanced force, the faster the change in the velocity of the object, but the greater the mass of the object, the slower the velocity changes. Quantitatively, the acceleration of an object can be predicted by dividing the net force acting on it by the mass of the object.

Often high school students learn to solve force problems without clearly relating the physical circumstances to the word problem presented. It is important to teach eighth grade students to identify mass, velocity, acceleration and forces, and to analyze how they are relating to each other in the physical system being studied. The ability to make qualitative predictions about what will happen next in these situations is the key to successful problem-solving that all physical scientists use before starting a calculation. Once the correct qualitative prediction is envisioned, a numerical solution is more likely to be correct. For example, students might be told that an opposing force is applied to a moving object being pushed along the ground and given all the needed numbers to calculate its final velocity. The students should correctly state that the object could slow down, could come to stop, and could even start moving backward prior to solving the problem numerically.

- g. Students know the role of gravity in forming and maintaining the shapes of planets, stars and the solar system.

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Gravity, an attractive force between masses, is responsible for forming our sun, the moons and the planets in our solar system into their spherical shape, and for holding it all together. It is also responsible for internal pressures in the sun, the earth and other planets and in the atmosphere. Newton asked himself if the force that causes objects to fall to the earth could extend to the moon. Newton knew that the moon should travel in a straight line (getting farther and farther from the earth) unless a force was acting on it to change its direction into a circular path.



He worked out the mathematics that convinced him that the force between all massive objects is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers. This relationship was then extended to explain the motion of the earth and the other planets about the sun.

Initially the universe consisted of light elements such as hydrogen, helium and lithium distributed in space. It was the attraction of every particle of matter for every other particle of matter that caused the stars to form, making it possible for the "stuff" of the universe to be created. As gravity is the fundamental force responsible for the formation and motion of stars and of the clusters of stars called galaxies, it controls the size and shape of the universe.

STANDARD SET 3: Structure of Matter

Background

There is no disagreement about the importance of understanding the structure of matter. Richard Feynman, a famous Nobel physicist, has said "If, in some cataclysm, all scientific knowledge were to be destroyed and only one sentence passed on.....I believe it is the atomic hypothesis (or atomic fact, or whatever you wish to call it) that all things are made of atoms - little particles that move around in perpetual motion attracting each other when they are a little distance apart, but repelling upon being squeezed into one another."

Teachers should assess students' knowledge prior to instruction of this topic, as the atomic theory of matter may be very challenging to them. Students are expected to recall terms and definition from earlier introductions to the concepts of atoms, molecules and elements. Instruction should provide empirical evidence for the atomic theory that is useful for understanding science and crucial to the study of chemistry.

When students are learning about the structure of matter, it should be emphasized that the historical evidence for atoms was based largely on indirect measurements and inferences far removed from direct experience. Recently, instruments have been built that produce images of

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individual atoms, confirming what was inferred earlier as a result of overwhelming evidence from many scientific experiments. Most scientists come to know the atomic theory is true by repeatedly using the concepts and principles presented in the theory to explain observed properties and predict changes in matter.

Text of the Standards

3. Each of the more than 100 elements of matter has distinct properties and a distinct atomic structure. All forms of matter are composed of one or more of the elements. As a basis for understanding this concept:

a. Students know the structure of the atom and how it is composed of protons, neutrons, and electrons.

Shortly after British physicist Ernest Rutherford inferred the existence of atomic nuclei, the general idea emerged that atoms are mostly empty space with a tiny, massive nucleus at the center containing positively charged protons and neutral neutrons. This nucleus is surrounded by tiny, negatively charged electrons, each with about 1/2000 the mass of a proton or neutron. Danish physicist Niels Bohr developed a model of the hydrogen atom to explain its visible spectrum. Knowing the historical importance of this model is a high school chemistry standard. Bohr's model succeeded in predicting the spectrum of light emitted by hydrogen atoms and is therefore the acknowledged starting point for understanding atomic structure. However, Bohr's "solar" model of the atom, diagrammed in most textbooks as showing electrons in circular orbits about the nucleus, is over-simplified. It is best not to try to describe how the electrons in an atom are moving but rather to help students develop a model of the atom in which each electron has a definite energy. Students should know that it is the energy of each electron in an atom that keeps it in motion around the positive nucleus to which it is attracted. The structure of multi-electron atoms is understood in terms of electrons filling energy levels that define "orbitals."

b. Students know that compounds are formed by combining two or more different elements and that compounds have properties that are different from their constituent elements.

The word "combining" implies bonding. Understanding the concepts of ionic and covalent bonding helps explain why some elements combine to form compounds and some don't, and why the chemical symbols for compounds are written as they are. Atoms of different elements combine to form compounds and a compound can and usually does have chemical characteristics and physical properties that are different from those of its constituent elemental atoms. Examples and generalizations can be drawn from ionic compounds formed of metals and non-metals, and covalently bonded, organic compounds formed from carbon and other elements.

Students often learn to manipulate chemical equations without having a picture in their minds of physical reality at the atomic level. The ability to create such a picture is a useful skill that helps students keep track of all the atoms in the process. For example, the reaction of methane and oxygen to form carbon dioxide and water can be visualized using models or drawing pictures for the atoms and molecules in the reactants. These molecules can then be rearranged into new products. (Make sure that all the atoms in the starting reactants are accounted for in the new products.) Instruction in this standard will promote imagining

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compounds as a collection of molecules and picturing a molecule as comprised of its constituent atoms. Knowing exactly how the atoms are organized to form the molecule is not essential.

- c. Students know atoms and molecules form solids by building up repeating patterns, such as the crystal structure of NaCl or long-chain polymers.

Crystals of table salt, the compound NaCl, has a regular, cubic structure in which sodium (Na^+) ions alternate with chlorine (Cl^-) ions in a three dimensional array with the atoms at the corner of cubes forming the lattice. In organic polymers, carbon, hydrogen and sometimes oxygen, and nitrogen atoms combine to form long, repetitive, string-like molecules. The dramatically different properties of salts and polymers, such as the ability to cleave a crystal but not polymers, or the flexibility of many polymers in contrast to the rigidity of all crystals, is evidence for these two models of atomic structure and types of bonds.

Inexpensive models of molecules can be made using colored gumdrops held together with toothpicks to represent molecules. Students can identify the atoms that comprise the molecules, given a color-coded key relating the color of the gumdrop to an atom of an element. They can also see that there are a number of ways to arrange atoms in a molecule. Students can be told that the shape of molecules is important to its chemical and physical properties. In high school they will be introduced to the ideas that shape is determined mainly by the electron configuration that provides the most energy stable system.

Students can also grow crystals from solution and should understand that this process leads to the building up of atoms into a lattice. Dissolve an excess of sodium chloride, sugar or Epsom salts in water. Hang a string in the water and allow the container to stand in a quiet place while the water evaporates. Crystals will form on the string. Hanging a small (seed) crystal tied to a piece of thread in the solution will accelerate the growth process. Crystal growing books and kits (including chemicals, glassware and instructions) are available commercially. Watch crystals grow on microscope slides under a microscope. Some crystals display vivid colors when viewed between crossed sheets of polarizing material.

- d. Students know the states of matter (solid, liquid, gas) depend on molecular motion.

All atoms are in constant motion. Subsequently all molecules are in constant motion. For any given substance the relative freedom of motion of its atoms or molecules increases from solids to liquids to gases. When we place a thermometer into a substance and measure its temperature we are measuring the average atomic or molecular energy of motion. The state of matter of a given substance is therefore dependent on the balance between the internal forces that would restrain the motion of the atoms or molecules and the random motions that are in opposition to these restraints.

The process of phase change is evidence of various degrees of atomic and molecular motion. The conditions of temperature and pressure under which most materials change from solid to liquid or liquid to vapor (gas) or gas to plasma have been measured. These properties are difficult to predict, but are highly reproducible for different samples of the same material and can be used to identify substances. Some substances will go from solid to gas directly at one atmosphere pressure. Dry ice, which is frozen carbon dioxide, is an example. Chemical handbooks contain the melting points (or freezing points) and boiling points (or condensation temperatures) of most materials usually under one atmosphere pressure. If the pressure is not

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one atmosphere, these temperatures change. It should be noted that some substances have more than one stable solid phase at room temperature. Graphite with its soft black texture and hard, clear crystalline diamond atomic structure are both solid phases of elemental carbon.

To use water as an example, at one atmosphere pressure, ice forms when water is cooled below zero degrees Celsius (or 32 degrees Fahrenheit). Above the freezing point the average molecular energy of motion of the water molecules is just enough to overcome the attractive forces between the molecules. The water molecules thereby avoid being locked in place and remain liquid. At and below the freezing point the water molecules become localized into the solid, crystalline material we call ice. When liquid water is heated to temperatures of 100 degrees Celsius, molecular motion increases until large groups of water molecules overcome the attractive forces between the molecules. At this point those energetic molecules form bubbles of steam which are bubbles of gas made not of air but of water. The process in which bubbles of water vapor escape from liquid water is called “boiling.” Continued heating will change the liquid water entirely into vapor instead of raising the temperature of the water above 100 degrees Celsius.

- e. Students know that in solids the atoms are closely locked in position and can only vibrate; in liquids the atoms and molecules are more loosely connected and can collide with and move past one another; and in gases the atoms and molecules are free to move independently, colliding frequently.

Atoms or molecules of a solid form a pattern that minimizes the structural energy of the solid consistent with the way the atoms or molecules attract at long distances but repel at short distances. The atoms or molecules vibrate about their equilibrium positions in this pattern. When raised above the melting temperature, the atoms or molecules acquire enough energy to slide past one another so that the material, now a liquid, can flow; the density of the liquid remains very close to that of the solid, giving evidence that in a solid or a liquid the atoms stay at about the same average distance.

If a single atom or molecule acquires enough energy, however, it can pull away from its neighbors and escape to become a molecule of a gas. Gas molecules move about freely and collide randomly with the walls of a container and with each other. The distance between molecules in a gas is much larger than in a solid or a liquid, and this can be emphasized when students study density.

- f. Students know how to use the periodic table to identify elements in simple compounds.

The Periodic Table of Elements is arranged horizontally in order of increasing atomic number (number of protons) and vertically in columns of elements with similar chemical properties. Students should learn to use the Periodic Table as a quick reference for associating the name and symbol of an element in compounds and ions. They should be able to find the atomic number and atomic weight of the element listed on the table. The Periodic Table is both a tool and an organized arrangement of the elements that reveals the underlying atomic structure of the atoms. This standard focuses on the table as a tool. Every field of science uses the Periodic Table. There are various forms of the Periodic Table. Astrophysicists may have a table that includes elemental abundances in the solar system. Physicists and engineers might use tables that include boiling and melting points or thermal and electrical conductivity of the

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elements. Chemists have tables that show the electron structures of the element. Students should be encouraged to refer to the Periodic Table as they study the properties of matter and learn about the atomic model.

STANDARD SET 4: Earth in the Solar System (Earth Science)

Background

Eighth grade students are ready to tackle the larger picture of galaxies and astronomical distances. They are ready to study stars compared and contrasted to our sun, and to learn in greater detail about the planets and other objects in our solar system. High school studies of earth science will include the dimension of time along with three-dimensional space in the study of astronomy.

Text of the Standards

4. The structure and composition of the universe can be learned from studying stars and galaxies and their evolution. As a basis for understanding this concept:

a. Students know galaxies are clusters of billions of stars and may have different shapes.

Stars are not uniformly distributed throughout the universe but are clustered by the billions in galaxies. Some of the fuzzy points of light in the sky that were originally thought to be stars are now known to be very distant galaxies. It appears that galaxies themselves form clusters that are separated by vast expanses of empty space. As galaxies are discovered they are classified by their differing sizes and shapes with the most common shapes being spiral, elliptical, and irregular. Beautiful, full color photographs of astronomical objects are available on the Internet, in library books, and in a number of popular and professional journals. It may also catch the interest of students to know that astronomers have inferred the existence of planets orbiting some stars.

b. Students know that the Sun is one of many stars in the Milky Way galaxy and that stars may differ in size, temperature, and color.

Our star, the sun, is located in the rim of a typical spiral galaxy called the Milky Way, and orbits the galactic center. In similar spiral galaxies this galactic center appears as a bulge of stars in the heart of the disk. The bright band of stars cutting across our night sky is an edge on view of the Milky Way. Stars vary greatly in size, temperature and color. For the most part, these variations are related to the star's life cycle. Light that comes to us from the sun and other stars indicates that the sun is a fairly typical star. It has a mass of about 2×10^{30} kg, and energy output, or luminosity, of about 4×10^{26} joules/sec. The surface temperature of the sun is approximately 5,500 degrees Celsius and the radius of the sun is about 700 million meters. It is the surface temperature that determines the yellow color of the light we see from the sun. Red stars have cooler surface temperatures and blue stars have hotter surface temperatures. To connect the surface temperature to the color of our sun or of other stars, obtain a "black-body"

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temperature spectrum chart from a high school or college textbook, or visit one of the educational web sites that deal with this topic.

- c. Students know how to use astronomical units and light years as measures of distance between the Sun, stars, and Earth.

Distances between astronomical objects are enormous. Units used in the laboratory or on field trips, such as centimeters, meters, and kilometers, are not useful. As a result, astronomers use other units to describe large distances. The astronomical unit (au) is defined to be equal to the average distance from the earth to the sun: $1 \text{ au} = 1.496 \times 10^{11}$ meters. Distances between planets of the solar system are usually expressed in au. For distances between stars and galaxies, even this large unit of length is not sufficient. Interstellar and intergalactic distances are expressed in terms of how far light travels in one year, the light year (ly): $1 \text{ ly} = 9.462 \times 10^{15}$ meters or approximately 6 trillion miles. The most distant objects observed in the universe are estimated to be 10 to 15 billion light years from our solar system. Help students become familiar with astronomical units (au) by expressing the distance from the sun to the planets in au's instead of meters or miles. A good exercise to become familiar with the relative distances of the planets from the sun is to lay out the solar system to scale on a length of cash register tape.

- d. Students know that stars are the source of light for all bright objects in outer space and that the Moon and planets shine by reflected sunlight, not by their own light.

The energy that we see from the sun and other stars as visible light is caused by nuclear fusion reactions that occur deep inside the star's core. By carefully analyzing the spectrum of light from stars, we know that most stars are composed primarily of hydrogen, a smaller amount of helium, and much smaller amounts of all the other chemical elements. Most stars are born from the gravitational compression and heating of hydrogen gas. A fusion reaction results when hydrogen nuclei combine to form helium nuclei. This releases energy and establishes a balance between the inward pull of gravity and the outward pressure of the fusion reaction products.

Ancient peoples observed that some objects in the night sky wandered about with respect to groups of other objects that maintained fixed positions with respect to each other (i.e., the constellations.) These "wanderers" are the planets. Through careful observations of their movements we know that planets travel in nearly circular (slightly elliptical) orbits about the sun.

Planets (and our moon) do not generate the light that makes them visible, a fact that is demonstrated during eclipses of the moon or by observing phases of the moon and planets when a portion is shaded from the direct light of the sun.

Manned missions to the moon, unmanned landers that have reached Venus and Mars, and fly-by satellite missions to other planets have provided information about their reflectivity, structure and composition.

- e. Students know the appearance, general composition, relative position and size, and motion of objects in the solar system, including planets, planetary satellites, comets, and asteroids.

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There are currently nine known planets in our solar system: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. They vary greatly in size and appearance. For example, the mass of the earth is 6×10^{24} kg and its radius is 6.4×10^6 m. Jupiter has more than 300 times the mass of Earth and its radius is 10 times larger. The planets also drastically vary in their distance from the sun, period of revolution about the sun, period of rotation about their own axis, tilt of their axis, composition, and appearance. The inner planets (Mercury, Venus, Earth, and Mars) tend to be relatively small and are composed primarily of rock. The outer planets (Jupiter, Saturn, Uranus and Neptune) are generally much larger in size, and composed primarily of gas. Pluto is composed primarily of rock and is the smallest planet in the Solar System. All planets are much smaller in size than the sun. All objects are attracted toward one another gravitationally and the strength of the gravitational force between them depends on their masses and the distance that separates them from each other and from the sun. Before Newton formulated his laws of motion and the law of universal gravitational attraction, German astronomer Johannes Kepler deduced three laws (Kepler's Laws) from astronomical observations that described the motions of the planets.

Planets have smaller objects orbiting them called satellites or moons. Earth has one moon that completes an orbit once every 28 days (approximately). Mercury and Venus have no moons, but Jupiter and Saturn have many moons. Very small objects composed mostly of rock (asteroids) and/or the ice from condensed gases (comets) also orbit the Sun. The orbits of many asteroids are relatively circular and lie between the orbital paths of Mars and Jupiter (the asteroid belt.). Some asteroids and all comets have highly elliptical orbits, causing them to range great distances from very close to the sun to well beyond the orbit of Pluto. Look for field trip opportunities for students to observe the night sky from an astronomical observatory or courtesy of a local astronomical society. A visit to a planetarium may be possible. If feasible, have students observe the motion of Jupiter's inner moons, as well as the phases of Venus. Using resources in the library media center, students can research related topics of interest.

STANDARD SET 5: Reactions

Background

When substances react, the atoms involved in the reactants are rearranged, resulting in products. Students have learned that the physical and chemical properties of the newly formed substances (products) are different from the physical and chemical properties of the original substances (reactants). Eighth grade students will learn that it is the underlying arrangement of the atoms in the reactants and products, and the energy needed or released during the rearrangement process that explain chemical reactions. Understanding chemical reactions is very important because a large portion of the discipline of chemistry has to do with them, directly or indirectly.

It is important to differentiate between a chemical change and a physical change. In a physical change one or more physical properties of the material are altered but the chemical composition, i.e., the arrangement of the atoms in molecules, remains the same. In a chemical change the atoms are rearranged to form new substances with different chemical and physical properties. It will be important for the students to be familiar with the Periodic Table and the names and symbols of the chemical elements.

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Students are prepared for the idea of chemical reactions in first grade when they learn that the properties of substances can change when they are mixed, cooled or heated. In third grade they learn that when two or more substances are combined, a new substance may be formed that can have properties that are different from those of the original materials. In fifth grade they learn that during chemical reactions, the atoms in the reactants rearrange to form products with different properties. The study begun on reactions in the eighth grade will support future studies about conservation of matter and stoichiometry as well as work on acids, bases and solutions. Students will go beyond studying reactions and their reactant/product relationships to work with the rates of reaction and chemical equilibrium. The student should be able to envision a chemical equation at the atomic and molecular level. They should “see” the number of reactant atoms and molecules in the equation coming together and by some process rearranging into the correct number of atoms and molecules that form the products. This is an important conceptual skill that helps students keep track of all the atoms.

Text of the Standards

5. Chemical reactions are processes in which atoms are rearranged into different combinations of molecules. As a basis for understanding this concept:

- a. Students know reactant atoms and molecules interact to form products with different chemical properties.

This standard focuses on changes that occur when atoms and molecules as reactants form product compounds with different chemical properties. Allow students to perform simple reactions or demonstrate the reactions for them. All students should be able to learn the more important chemical reactions and the elements involved in them, especially if common compounds such as vinegar (acetic acid), baking soda (sodium bicarbonate) table salt (sodium chloride), carbonated water, nutritional minerals and foods are used in activities or demonstrations. An example might be adding calcium chloride and baking soda and water. Reactions such as these demonstrate clearly the differences in properties between products (solids and liquid) and reactants (solid, liquid and gas).

- b. Students know the idea of atoms explains the conservation of matter: in chemical reactions the number of atoms stays the same no matter how they are arranged, so their total mass stays the same.

The conservation of matter is a classical concept, reinforcing the idea that atoms are the fundamental building blocks of matter. Atoms do not appear or disappear in traditional chemical reactions in which the constituent atoms and/or polyatomic ions are simply rearranged into new and different compounds. Conservation of atoms is fundamental to the idea of balancing chemical equations. The total number of atoms of each element in the reactants must equal the total number of atoms of each element in the products. The total number of atoms, hence the total mass, stays the same before and after the reaction.

There are a number of ways to teach and assess students’ understanding of the concept of conservation of mass in chemical reactions. Weighing reactants before and products after a reaction shows that mass is neither gained nor lost. However, it should be noted that

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experimental errors are possible; the most common is not sufficiently drying the products before weighing. One simple demonstration of the concept that atoms, hence matter, is conserved in chemical reactions where mass might appear to be lost is to determine the combined mass of a small sealed container one-third filled with water, its screw-on cap, and one-quarter of an effervescent tablet. Drop the piece of tablet in the water and immediately seal the container. After the fizzing has stopped, the combined mass of the sealed container and the tablet should remain the same. After the seal is broken, much of the carbon dioxide gas formed by the reaction escapes and the mass of the container and its contents decreases.

Students should also be taught to balance simple chemical equations. This reinforces the idea that atoms do not appear or disappear in chemical reactions, and, hence, that matter is conserved.

c. Students know chemical reactions usually liberate heat or absorb heat.

In chemical reactions, the atoms in the reactants rearrange to form products and there is usually a net-change in energy. Breaking bonds between atoms requires energy; making a bond releases it. If the total making and breaking of all bonds for a particular chemical reaction results in a net release of energy, the reaction is said to be exothermic. This energy is typically released as heat into nearby matter. If the total making and breaking of bonds results in a net absorption of energy, this energy is typically absorbed as heat from nearby matter which therefore cools. These reactions are called endothermic. A convenient way to demonstrate that chemical reactions liberate or absorb heat is to demonstrate the hot packs or cold packs used for athletic injuries. The change in temperature produced may be from a chemical reaction or it may be caused by a "heat of solution" and not by a chemical reaction. Dissolving is a physical and not a chemical change since the compound may be recovered, unchanged chemically, by evaporation.

d. Students know physical processes include freezing and boiling in which a material changes form with no chemical reaction.

When heated, many solid materials undergo a reversible change of state into a liquid by melting. Under the standard condition of one atmosphere of pressure, the temperature at which such a solid material melts is the same as the temperature at which the liquid material freezes and this temperature, called "the melting point," is characteristic of the material. Many liquid materials when heated also undergo a reversible change of state into a gas. Under one atmosphere of pressure, such a liquid material may boil; the temperature at which this occurs is also characteristic of the material and is called "the boiling point." Such reversible changes back and forth from solid to liquid, or from liquid to gas, are labeled as physical changes because no chemical change -- a permanent reordering of the atoms into new molecules -- occurs. Similarly the dissolving of one substance into another, like a solid or gas into a liquid, is often reversible (by evaporating the liquid to leave the solid, or heating the liquid to drive out the gas), and is also labeled a physical rather than a chemical change. A change in state may accompany some chemical reactions. Activities such as mixing iron filings with sand demonstrate a physical change. Physical changes can usually be undone to recover the original materials unchanged. In this case a magnet can recover the iron filings from the mixture.

e. Students know how to determine whether a solution is acidic, basic or neutral.

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Indicators that change color are routinely used to determine whether a solution is acidic, basic or neutral. There is a numerical pH scale, related to the concentration of hydrogen ions in the solution, that also characterizes a solution as acidic (lower than 7), basic (higher than 7) or neutral (near 7). There are electrodes and electronic instruments which can measure the pH of a solution directly. Some acids and bases are defined other than by their hydrogen ion concentration but these will be dealt with in high school chemistry. Give students the opportunity to test solutions, including foods such as fruits and vegetables, with pH paper or litmus paper or indicator solutions or pH meters to determine if a solution or food is acidic, basic or neutral. They should be familiar with the pH scale to know what a given pH value indicates.

STANDARD SET 6: Chemistry of Living Systems (Life Science)

Background

As all living organisms are made up of atoms, chemical reactions take place continuously in plants and animals, including humans. The uniqueness of organic chemistry stems from “chain polymers.” Life could not exist, as we know it without the ability of some chemicals to join together, repetitively, to form large, complex molecules. Concepts learned in this standard set are critical for understanding fully the chemistry of the cells of organisms, genetics, ecology, and physiology that will be taught in the high school biology/life sciences standard sets.

Text of the Standards

6. Principles of chemistry underlie the functioning of biological systems. As a basis for understanding this concept:
- a. Students know that carbon, because of its ability to combine in many ways with itself and other elements, has a central role in the chemistry of living organism.

Carbon is unique among the elements in its ability to link to itself in long chains while at the same time linking to many other elements. This makes it possible to create many different kinds of large, carbon-based molecules. Typically carbon will make four separate covalent bonds, but double and triple bonds are also possible. The variety of bonds allows carbon-based molecules to have a wide range of shapes and chemical properties. Students can research the nomenclature, composition and structure of organic molecules from books and the Internet. They can also construct models of these structures with colored gumdrops or mini-marshmallows and toothpicks, or with Legos. Carbon atoms can be assigned one color and other elements, other colors. The mnemonic HONC may be useful, i.e., H bonds 1, O bonds 2, N bonds 3 and C bonds 4.

- b. Students know that living organisms are made of molecules consisting largely of carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur.

Living organisms are made up of a great variety of molecules consisting of many atoms (with carbon atoms playing key roles), but the number of different elements involved is quite

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small. Carbon plus only five other elements make up most of Earth's biomass. These six elements however, can combine in many different ways to make large, organic molecules and compounds. To demonstrate this, burn organic material such as bone, leaves, wood or a variety of candles. Hold a cold glass or plate above the flame to condense droplets of water, one of the combustion products. Hold a heat-treated glass in the flames to collect carbon deposits in the form of soot. Ask students what elements were in the organic material. Call attention to the black material that forms when meat is roasted or grilled, or when toast is charred.

c. Students know that living organisms have many different kinds of molecules including small ones, such as water and salt, and very large ones, such as carbohydrates, fats, proteins, and DNA.

Living organisms require a variety of molecules, some of them containing carbon and some not. The molecules that make up organisms and control the biochemical reactions that take place within them are usually large molecules such as DNA, proteins, carbohydrates, and fats. Organisms also require simple substances such as water and salt to support their functioning. Encourage students to research why plants and animals need simple molecules like water. Squeeze the water out of celery or turnips to demonstrate where the water is. Ask students how they can demonstrate that water is in fruits and vegetables (e.g. dried fruit). Ask students how they know that there is salt in their bodies. Most of them know that their perspiration tastes salty.

STANDARD SET 7: Periodic Table

Background

Students will need to know the chemical symbols for the common elements. It will be helpful for them to be familiar with other properties of materials such as melting temperatures, boiling points, density, hardness, thermal and electrical conductivity. By the time students have come to Standard Set 7, they should be used to seeing the Periodic Table and should know the names and chemical symbols of most of the common elements. Now in Standard Set 7 they must look in greater detail and learn the significance of atomic numbers and isotopes and how they relate to the classification of elements. Students need to go more deeply into the elemental properties that serve as the basis for the periodic arrangement. Meeting the standards in Set 7 will serve as a strong preparation for the study of atomic and molecular structure and the relationship between these structures and the arrangement of elements on the Periodic Table of Elements that will come in high school chemistry.

There is a common form of the Periodic Table with 18 columns (groups of elements) in the main body. It is this form that shows the "periodicity" or repeating pattern of chemical and some physical properties of the elements. What varies most in published Periodic Tables is the information provided in the box that represents each element. There are many web sites where interactive Periodic Tables can be found. The most useful tables are those that provide physical properties of the most common form of the element in addition to atomic number and atomic weight are most useful. A table that color-codes metals and non-metals is also useful.

Elements toward the top of the Periodic Table are lighter, and those toward the bottom are heavier. Elements to the left are generally metallic in nature and those toward the right are

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non-metallic. The word metallic refers to the collective properties of luster, malleability, high electrical and thermal (heat) conductivity that we have come to associate with common metals in our everyday experience. While the majority of elements in the Periodic Table are metals, a few are classified as semi-metals and can be found bordering the transition between the metals and non-metals. When atoms from the left side of the table combine with atoms from the right side they tend to form ionic salts which are brittle crystalline compounds with high melting temperatures.

In high school students will learn that the arrangement of the elements in the columns of the Periodic Table reflects the electron structure of the atoms of each element. This explains the similarity in the chemical properties of the elements in each column of the Periodic Table.

Students should be able to readily use the Periodic Table to find the atomic number of an element and should know that there is a pattern of increasing atomic numbers as you read from left to right moving down one row at a time. The lanthanides and actinides are moved off the table to save space but if placed in the table they would follow the same pattern of reading left to right and then down. Students should also know that the atomic number is the number of protons in the nucleus.

Text of the Standards

7. The organization of the periodic table is based on the properties of the elements and reflects the structure of atoms. As a basis for understanding this concept:

a. Students know how to identify regions corresponding to metals, nonmetals and inert gases.

The Periodic Table of Elements is structured so that metals are on the left, with the most reactive metals on the far left. Non-metals are located on the right with the most reactive next to the “inert” gases on the far right. Despite the name, inert gases are not truly inert. Although no naturally occurring inert gas compounds are known, some have been synthesized in the laboratory. Because of this, most scientists use the term “noble” gas instead of inert gas. Semi-metals, found in the Periodic Table between the metals and non-metals, are elements, such as silicon, that have some properties of metals but also have properties that are typical of non-metals. Although there are only a few elements that fit this category, the unique electrical property of semi-metal elements is that they are semiconductors, an essential property for computer “chips. The rare earth elements can be used to produce very strong magnets. Students should know that scientists have the right to name their discoveries and that some elements have been named after famous men and women scientists, such as Curium, Einsteinium and Seaborgium.

b. Students know each element has a specific number of protons in the nucleus (the atomic number) and each isotope of the element has a different but specific number of neutrons in the nucleus.

A rigorous definition of the term "element" is based on the number of protons in the atom's nucleus (the atomic number). All atoms of a given element have the same number of protons in the nucleus. Atoms with different atomic numbers are atoms of different elements.

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Although the number of protons is fixed for a particular element, the same is not true for the number of neutrons in the nucleus. Atoms of an element that have different numbers of neutrons are called isotopes of the element. For example, all hydrogen atoms have one proton in the nucleus but there are two additional isotopes of hydrogen with different numbers of neutrons. One is called deuterium (one proton and one neutron), and the other is called tritium (one proton and two neutrons). The common isotope of hydrogen has one proton and no neutrons in its nucleus.

Some isotopes are radioactive, meaning that the nucleus is unstable and can spontaneously emit particles or trap an electron to become the nucleus of a different element with a different atomic number. For some elements all of their isotopes are radioactive, such as the element with atomic number 43, technetium, or the element with atomic number 86, radon, and no stable samples of these elements exist. Element 92, uranium, is another example of where no stable isotopes exist. However, uranium (238) is found in nature because it decays so slowly that it is still present in the earth's crust from the time the earth was created. Because the atomic number of each element represents the number of protons in the nucleus, as the atomic number increases the mass of the atoms of succeeding elements generally increases. This, however, is not always true because of varying numbers of neutrons in some isotopes. In general, the atoms of the elements increase from left to right and those listed in the lower rows of the table are more massive than those in the upper rows.

c. Students know substances can be classified by their properties, including their melting temperature, density, hardness, and thermal and electrical conductivity.

The physical properties of substances reflect their chemical composition and atomic structure. The melting temperature or hardness of the common forms of the elements is related to the forces that hold the atoms and molecules together. Compare the boiling points of carbon and nitrogen. Carbon is solid up to very high temperatures (3,600 degrees Celsius) and nitrogen, the element next to it, is a gas until it is cooled to over 196 degrees Celsius below zero. This dramatic difference between two adjacent elements on the Periodic Table shows there must be very different intermolecular forces acting as a result of a slight change in atomic structure.

The electrical and thermal conductivity is strongly dependent on how tightly electrons are held to individual atoms. Metals and nonmetals can be found in regions of the Periodic Table. Metal atoms combine in regular patterns in which some electrons are free to move from atom to atom, which explains both large electrical and thermal conductivity.

Density is mass per unit volume and is a function of both the masses of individual atoms and the closeness with which they are packed.

STANDARD SET 8: Density and Buoyancy

Background

The central goal of this standard set is to be able to answer the simple question, "Will it sink or will it float?" Students will learn that density is a physical property of a substance independent of how much of it is available and they will be able to relate the property of density to the phenomenon of buoyancy. Archimedes, a Greek living on the island of Sicily, is credited with first recognizing that different substances have different densities and that fluids exert a

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buoyant force on objects submerged in them. He came to this understanding while trying to determine what else was in a supposedly gold crown. Put simply, Archimedes realized that water does not sink in water. That is, if you focus on one drop of water within water in a larger container, (and assuming that you could keep the drop intact and distinct) the drop would not fall, even though it has weight. The surrounding water must exert an upward buoyant force on the drop equal to the weight of the drop. The drop would fall if its weight were greater than the buoyant force supplied by the surrounding water. The drop would rise if it weighed less than the buoyant force. The surrounding water exerts an upward buoyant force on any volume within it equal to the weight of that volume of water. Understanding the nature of floating and sinking led Archimedes to realize that different substances have different densities, the key to solving whether the crown was gold or a fake.

Density is a property characteristic of the material itself and does not change if the material is subdivided or if the amount available is altered. Since different substances have different densities, knowing the density of a sample is very useful in determining its composition. For example, the composition of the earth's interior was first inferred to be different from that of rocks in the lithosphere because the density of lithospheric rock is different from the average density of the earth.

The density of solids and liquids, the two condensed states of matter, does not vary much with changes in pressure or temperature. But small differences in density within a liquid or gas caused by local heating can occur, causing convection currents.

As for gases, because they are so compressible, their densities can vary over a wide range of values. This is why tables of measured values of density are found only for solids and liquids.

Most fluids (gases and liquids) are very poor conductors of heat. Normally, fluids expand when their temperature increases because of the more rapid motion of their constituent molecules. If a fluid is heated locally, the thermal energy is not conducted rapidly to other parts of the fluid and the region that is hotter expands, becoming less dense than the cooler surrounding fluid. The buoyant force supplied by the surrounding cooler fluid on the hotter expanded region is greater than the weight of the hotter region. This causes the hotter less dense region of fluid to be pushed up, a phenomenon usually simplified as: "Hot air rises."

A thorough understanding of density and buoyancy will be helpful in mastering the high school earth science standards.

Text of the Standards

8. All objects experience a buoyant force when immersed in a fluid. As a basis for understanding this concept:

a. Students know density is mass per unit volume.

Density is a physical property of a substance independent of the quantity of the substance. A cubic centimeter of a substance has the same density as a cubic kilometer. Density can be expressed in terms of any combination of measurements of mass and volume. The dimensions most commonly used in science are grams/cubic centimeter for solids and grams/milliliter for liquids.

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- b. Students know how to calculate the density of substances (regular and irregular solids and liquids) from measurements of mass and volume.

Density is calculated by dividing the mass of some quantity of material by its volume. Mass can be determined by placing the material on a balance or scale and subtracting the mass of its container. The volume of a liquid can be measured easily using graduated cylinders and the volume of a regular solid with a ruler and appropriate geometric formula. It is not so simple, however, to measure the volume of an irregular solid. The volume of an irregularly shaped solid object may be determined by water displacement.

- c. Students know the buoyant force on an object in a fluid is an upward force equal to the weight of the fluid the object has displaced.

Whether or not an object will float depends on the magnitude of the buoyant force of the surrounding fluid (liquid or gas) compared to the weight of the object. The buoyant force is equal to the weight of the volume of fluid displaced by the object. The net force acting on a submerged body is the difference between the upward buoyant force of the surrounding fluid and the downward pull of gravity on the object (its weight). The same relationship applies to two fluids of differing densities, if they do not mix. Thus, if the volume of the fluid displaced by a submerged solid object weighs more than the object, the object will rise to the surface and float. If the values are the same, the object is said to be neutrally buoyant and will neither sink nor rise to the surface. If the volume of the surrounding fluid displaced by a solid object weighs less than the object, the object will sink.

The buoyant force can be demonstrated convincingly by placing a volume of water (e.g., a water-filled, sealed baggie) in a container of water and noting that the baggie filled with water does not sink even though gravity applies a downward force on the water-filled baggie (its weight). Therefore, there must be an upward, buoyant force applied by the surrounding water. If the baggie is filled with a liquid that weighs more than an equal volume of water, it will sink. If liquid in the baggie is less dense than water, it will float. Have students fill another baggie with hot water to demonstrate that it floats in room temperature water. Fill a third baggie with ice water and repeat the experiment to show that colder water will sink in room temperature water.

A different and dramatic way to demonstrate buoyant forces is by placing a heavy object, such as a large rock, in a large container of water and asking students to first lift the object in the container without removing the object from the water, and then to lift the object completely out of the water. Students are usually startled by how much easier it is to lift the object when it is in a container filled with water than to lift that same object out of the water. People can move heavy stones from one place to another in rivers and lakes but they often could not lift the stone out of the water. A small beach ball pushed down into a large container of water produces the same effect in reverse for students who have never experienced the large buoyant force that water can exert on a volume that is mostly air.

- d. Students know how to predict whether an object will float or sink.

The most direct way to predict whether a substance or solid object will sink or float in a fluid is to compare the density of the substance or object to the density of the fluid, either by

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measurement or by looking up the values on a table of densities. If the object is less dense than the fluid, it will float. Materials with densities greater than that of a liquid can be made to float on the liquid (e.g., steel boats and concrete canoes floating on water) if they can be shaped to displace a volume of the liquid equal to their weight before submerging completely.

The density of liquids can be determined using a hydrometer, either commercially available or made from a pencil with a thumbtack in the eraser. The depth that an object of uniform density will sink in a liquid is a relative measure of the density of the liquid. Simple hydrometers, based on this principle, can be used to compare the densities of a variety of liquids to that of water. The length of the hydrometer submerged in an unknown liquid (U) compared to the length submerged in water (W) can be used to determine the density of an unknown liquid (W/U) in metric units of grams per cubic centimeter. How far a pencil hydrometer sinks in water can be marked as “1 gram per cubic centimeter”. If the pencil sinks twice as far in another liquid, its density is .5 gram per cubic centimeter; if it sinks half as far, the density is 2 grams per cubic centimeter, etc.

Air is also a fluid and exerts a buoyant force on objects submerged in it. Hot air balloons rise because the upward buoyant force of the cooler surrounding air is greater than the weight of the hot less-dense air inside the balloon and the trappings of the balloon. Helium balloons rise because a volume of helium gas is much lighter than an equal volume of air at the same temperature and pressure.

STANDARD SET 9: Investigation and Experimentation (I & E)

Background

Experiments can give consistent reproducible answers but, for many reasons, the answers may be incorrect or off the mark. By the time students complete the eighth grade they should have a foundation in experimental design and be able to use logical thinking processes to evaluate experimental results and conclusions. Mathematical representation of data is the key to quantitative scientific predictions. Graphs expressing linear relationships utilize proportional reasoning and algebra. Students should be taught to apply their knowledge of proportions and algebra to the reporting and analysis of data from experiments.

Text of the Standards

Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept, and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will:

- a. Plan and conduct a scientific investigation to test a hypothesis.
- b. Evaluate the accuracy and reproducibility of data.
- c. Distinguish between variable and controlled parameters in a test.
- d. Recognize the slope of the linear graph as the constant in the relationship $y = kx$ and apply this principle in interpreting graphs constructed from data.
- e. Construct appropriate graphs from data and develop quantitative statements about the relationships between variables.

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- 1 f. Apply simple mathematical relationships to determine a missing quantity
2 in a mathematic expression, given the two remaining terms
3 (including speed = distance/time, density = mass/volume, force = pressure x
4 area, volume = area x height).
5 g. Distinguish between linear and non-linear relationships on a graph of data.
6